THE APPLICATION OF RECENT TECHNIQUES IN FLIGHT FLUTTER TESTING

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SUMMARY

A flight test program is instituted in order to evaluate the applicability of two recent flight flutter testing methods. These methods are the random decrement (randomdec) and autocorrelation techniques. The relative merits of each method are based on analyzing response data obtained by sinusoidal and random excitation. A parameter identification digital program, using least squares approach, is developed to determine the aeroelastic characteristics of a two mode system. To date, the final results of the two types of excitation have been obtained primarily by the randomdec method. Therefore, this paper is limited to discussions and recommendations based on these results.

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INTRODUCTION

The Gates Learjet Corporation (GLC), a relative newcomer to the general aviation field, has consistently upgraded the flight flutter testing techniques used during aircraft certification. For instance, sinusoidal excitation of the control surfaces has replaced the pilot impulse technique; application of the shake and stop approach has produced decay responses of better quality; and additional stability criteria, such as the amplitude response and flutter margin (ref. 1), have become possible. Further improvements have recently been made feasible by the acquisition of new computer equipment. It is anticipated that the facility improvement will facilitate implementation of recent data reduction techniques resulting in reduced program costs and time delays.

A survey of the available literature was made in order to classify the various approaches which have been used or proposed. The autocorrelation and randomdec methods showed the greatest promise for possible implementation. As a result, a program was initiated to investigate the relative merits of these two methods. This comparative investigation was to be based on actual random and sinusoidal flight response data obtained on a Learjet Model 25; the ultimate objective being to recommend a particular technique for use in future flight flutter testings.

Most of the analysis has been done using the randomdec approach. Therefore, the major portion of this paper is devoted to discussions, evaluations, and recommendations based on these results. This paper presents these discussions along with the problems encountered.

PROGRAM DESCRIPTION

This section of the paper presents an overall description of the flight test program, computer program, and data reduction procedure.

Flight Test Program

Flight testing was planned with two objectives in mind. The first objective was to obtain actual flight test data for this program. The second objective was to gain insight regarding the relative merits of sinusoidal excitation versus random atmospheric turbulence.

The test airplane was a Learjet Model 25B (figure 1). Briefly, this model is a small, high performance business jet with a speed envelope of 350 knots and Mach .86. Main exterior features include a T-tail, two jet engines installed on the aft fuselage, and two large fuel tanks permanently mounted on the wing tips.

For test purposes, the airplane was fitted with two accelerometers on each tip tank and a potentiometer on each aileron, calibrated to measure aileron position. Aileron sinusoidal excitation was provided by input of a voltage signal of variable frequency into the autopilot roll servos.

An airborne recording system was used to record structural response data. Accelerometer outputs were processed through a GLC 1250 signal conditioner, converted to pulse duration modulation with a Vector 527 encoder, and recorded on magnetic tape by a Honeywell 5600 tape recorder.

The flight test procedure consisted of recording response data for three types of excitation. At each test speed, the plan called for obtaining two-minute recordings of random response data due to atmospheric turbulence, sinusoidal response data for a frequency range of 1.5 to 10 cycles per second and transient response data due to aileron pulses by the pilot. The test speeds ranged from 250 to 350 knots at an altitude of 4.57 km (15,000 ft) with full fuel in the wing and tip tanks.

Computer Program

This section describes briefly the computer program developed in order to analyze response data from a single channel transducer. The computer system (figure 2) is a Varian 620L with accessories such as ASR-33 Teletype, Tektronix 4010 Cathode Ray Tube (CRT), Pertec 6X40 Tape Drive and Statos 31 Printer/Plotter. The program includes subroutines capable of generating three kinds of randomdec signatures and a system identification parameter routine using a least squares approach.

The randomdec methods are based on Cole's and Houbolt's techniques described in refs. 2 and 3, respectively. These methods are as follows:

Option 1: Cole's approach of triggering each time the response crosses a preselected level, regardless of the sign of the slope (figure 3a).

Option 2: Cole's approach of triggering each time the response crosses zero with a positive slope (figure 3b).

Option 3: Houbolt's approach of triggering each time the response crosses zero with a positive slope, and triggering and inverting each time the response crosses with a negative slope (figure 3c).

The least squares approach follows the technique given in ref. 4. The program is capable of deducing the aeroelastic properties of both a one- and two-degree-of-freedom system, buried in a randomdec signature or an autocorrelation function. The latter is not a part of the computer program, and is obtained using an autocorrelation analyzer.

Data Reduction Procedure

The data reduction procedure was established based on both an extensive checkout of the program and the guidelines suggested by Chang (ref. 5). The data used for the checkout was obtained from a typical flight flutter test having two closely spaced modes.

Initially, the engineer monitors the response data displayed on the CRT, and then exercises an option to use all or part of the time history record. The next step is to choose one of the three randomdec options and to initiate the analysis using the selected response data. At the same time the randomdec averaging process is progressing, the program is conveniently displaying the signature generation on the CRT. Once convergence is achieved, the user may discontinue the averaging process and then proceed to curve fit a preselected length of the randomdec signature.

The proper signature length to be curve fitted is usually chosen based on a detailed analysis of the data obtained at the initial test speed. The recommended procedure is to curve fit different segments of the converged randomdec signature, and to plot damping and frequency values of the simulated modes versus signature length. Based on the constant behavior of these parameters and on a computed normalized standard deviation of the curve fit, the engineer can adequately select a signature length which assures him of reliable results.

To use this program, the engineer is required to input initial estimates of the unknown parameters to be determined. These parameters are frequency, damping ratio, amplitude, phase angle, and zero offset. Through an iterative process, the program solves for the final parameters which best match the experimental data. The closer the assumed parameters are to the actual values, the more likely convergence will occur.

RESULTS AND DISCUSSIONS

The procedure outlined in the previous section has been applied to response data obtained at one wing location using sinusoidal and random excitation. The sinusoidal and random results are first discussed separately and then compared with those obtained by the pilot pulse for final evaluation.

In line with the recommended data reduction procedure, the sinusoidal response data obtained at 250 knots was analyzed first in order to select the proper length of the randomdec signature. The randomdec signature was determined using Houbolt's technique (option 3) and was curve fitted for signature lengths of .45, .9, 1.35, 1.8 and 2.2 seconds. The curve fit analysis was performed to deduce the modal properties of the first and second wing antisymmetric modes. The results are shown in figure 4.

A study of figure 4 reveals that the two natural frequencies and the damping coefficient of the second mode are fairly constant with signature length. The damping coefficient of the first mode, on the other hand, shows inconsistent behavior at first, but then tends to stabilize for signature lengths between 1.6 and 2.2 seconds. Results from a similar analysis at 350 knots tend to confirm these observations (figure 5). Consequently, a signature length of 1.8 was selected.

The above analysis was repeated at 250 knots using Cole's zero crossing method (figure 6). This figure indicates that both options 2 and 3 yield roughly equivalent values.

Having established the proper signature, a complete analysis was conducted on the sinusoidal response data obtained at each test speed. Figure 7 shows the results of the analysis at 250 knots using option 3. As shown, figure 7a is the measured response due to sinusoidal aileron oscillation and figure 7b shows the converged randomdec signature. Figure 7c is a plot of the selected length of this signature (symbolized by X) and of the simulated signature shown as a solid line. The SD in figure 7c indicates the percent of the normalized standard deviation. This parameter is a measure of how well the theoretical curve fits the experimental data. The curves presented in figures 7d and 7e are the simulated decay responses of the two modes extracted by this analysis. The results of a similar analysis at 350 knots are shown in figure 8.

Some difficulties, due to flight testing problems, were experienced in the analysis of the random response data. Lack of atmospheric turbulence during this flight test necessitated a long search for an area with adequate turbulence, and as a result, this part of the test was conducted under very rough air conditions. Thus, the desired two minutes of random response records were difficult to obtain. The flight records obtained were so short that they were almost inadequate for the purpose of this study. However, in spite of these problems, an attempt was made to analyze the longest response record. This record consisted of 15 seconds of data at 350 knots.

Figure 9 presents the results of this analysis. Convergence of the randomdec was never achieved. As shown, only the second mode was predicted. All attempts to deduce the first mode failed. This was possibly due to the predominance of the second mode, as might be seen in the random response data (figure 9a). The natural frequency predicted seems to be reasonable but the damping is on the low side. In any case, the poor quality of the signal analysis, as indicated by the poor curve fit and the high SD (figure 9c), needs to be improved before any confidence is placed in the results. Such improvement might be achieved by incorporating a band-pass filter in the system, as described in reference 6.

As a final check on the results determined by the randomdec method, the 350 knot transient response data obtained using pilot pulse was analyzed. The method of analysis was the peak amplitude method. Basically, an envelope of the peaks and troughs of the free decay was sketched. The height between the envelope lines was then measured at each peak or trough. The logarithm of the height was plotted against the number of the wave (figure 10) and the best straight line was then drawn through the first part of the curve. The slope of this line was used to determine the damping ratio.

The results obtained at 350 knots by the peak amplitude method and the randomdec technique, using the random and sinusoidal response data, are summarized in Table 1. Also, the frequencies obtained by ground vibration testing are included in this table. A review of this information reveals that all methods compare well on frequencies. The randomdec method, using sinusoidal excitation, gives damping values for the second mode that agree well with those obtained from the peak amplitude analysis. With regard to the first mode, only the randomdec with sinusoidal excitation yielded damping values. However, on the basis of the small SD parameters and the reasonable results of the second mode, one cannot help but assume that the results obtained by the randomdec method, using sinusoidal excitation, are correct.

This same conclusion cannot be drawn from the results of the randomdec using random excitation. This is due to the fact that the randomdec signature had never converged nor was a good curve fit ever obtained.

CONCLUSIONS

The following conclusions can be stated on the basis of the discussions and results presented in this paper.

1. The application of the randomdec method using sinusoidal excitation appears to be a reasonable technique for use in flight flutter testing.

2. Although air turbulence is present in isolation, the problem of finding it during a flight flutter test makes its feasibility, as a source of excitation, questionable.

3. The use of the randomdec method using random excitation might be improved by utilizing a band-pass filter.

4. A least squares curve fit routine seems to be an efficient and accurate method for determining modal properties of a two mode system.

REFERENCES

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5. Chang, C.S.: Study of Dynamic Characteristics of Aeroelastic Systems Utilizing Randomdec Signatures. NASA CR-132563, 1975.

6. Brignac, W.J.; Ness, H.B.; Smith, L.M.: The Random Decrement Technique Applied to the YF-16 Flight Flutter Tests. AIAA Paper No. 75-776, presented at the AIAA/ASME/SAE 16th Structures, Structural Dynamics, and Materials Conference, Denver, Colorado, May 1975.

VELOCITY-KNOTS	METHOD	RESPONSE DATA	FREQUENCY--HZ		DAMPING RATIO	
			MODE 1	MODE 2	MODE 1	MODE 2
0	GROUND VIBRATION TEST	CO-QUAD	5.7	6.56	-	-
350	PEAK AMPLITUDE	FREE DECAY	-	6.34	-	.047
	RANDOMDEC	SINUSOIDAL	5.3	6.27	.037	.0488
	RANDOMDEC	RANDOM	-	6.2	-	.034

Table 1 Comparison of Results at 350 Knots

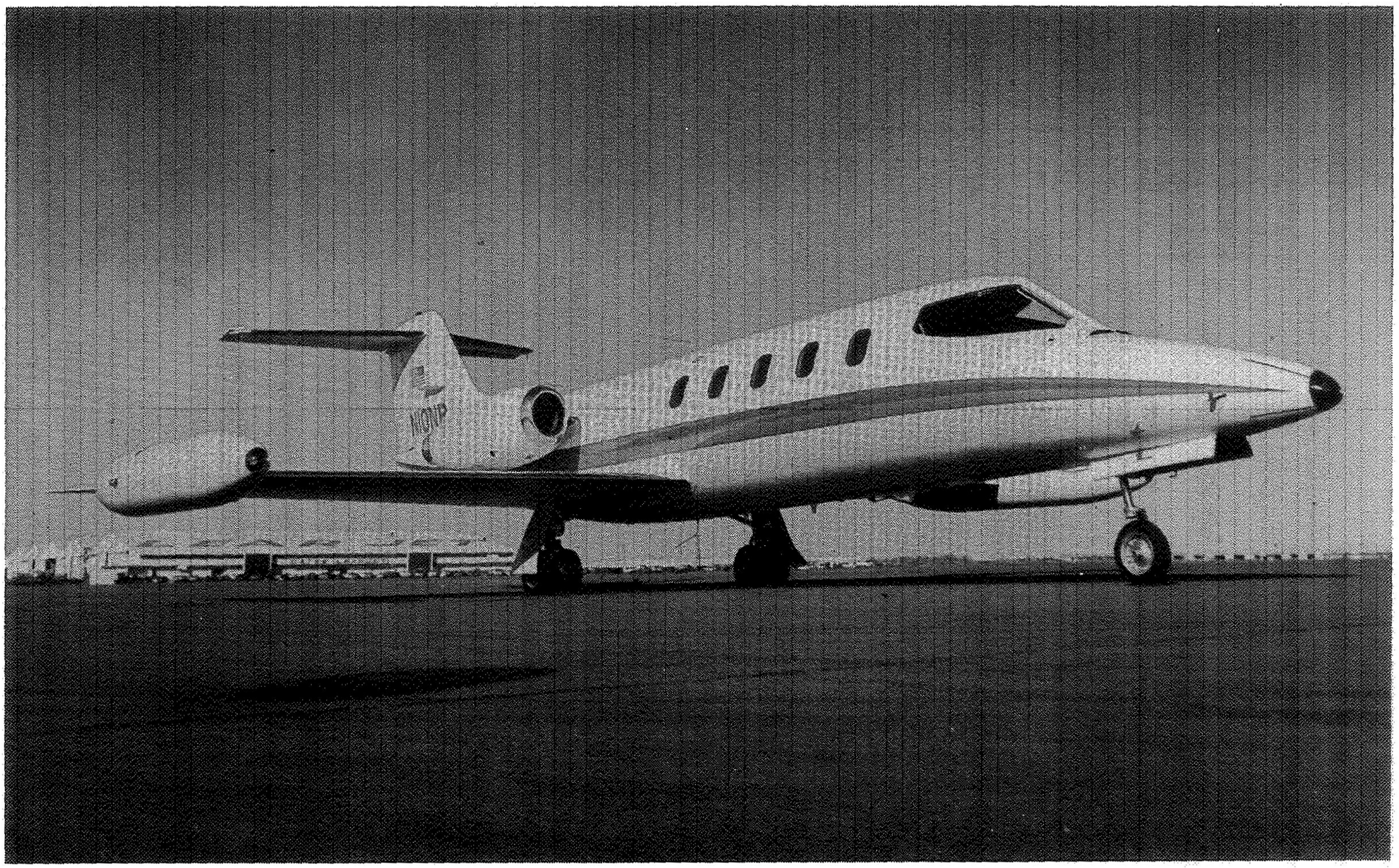

Figure 1.- Learjet model 25B.

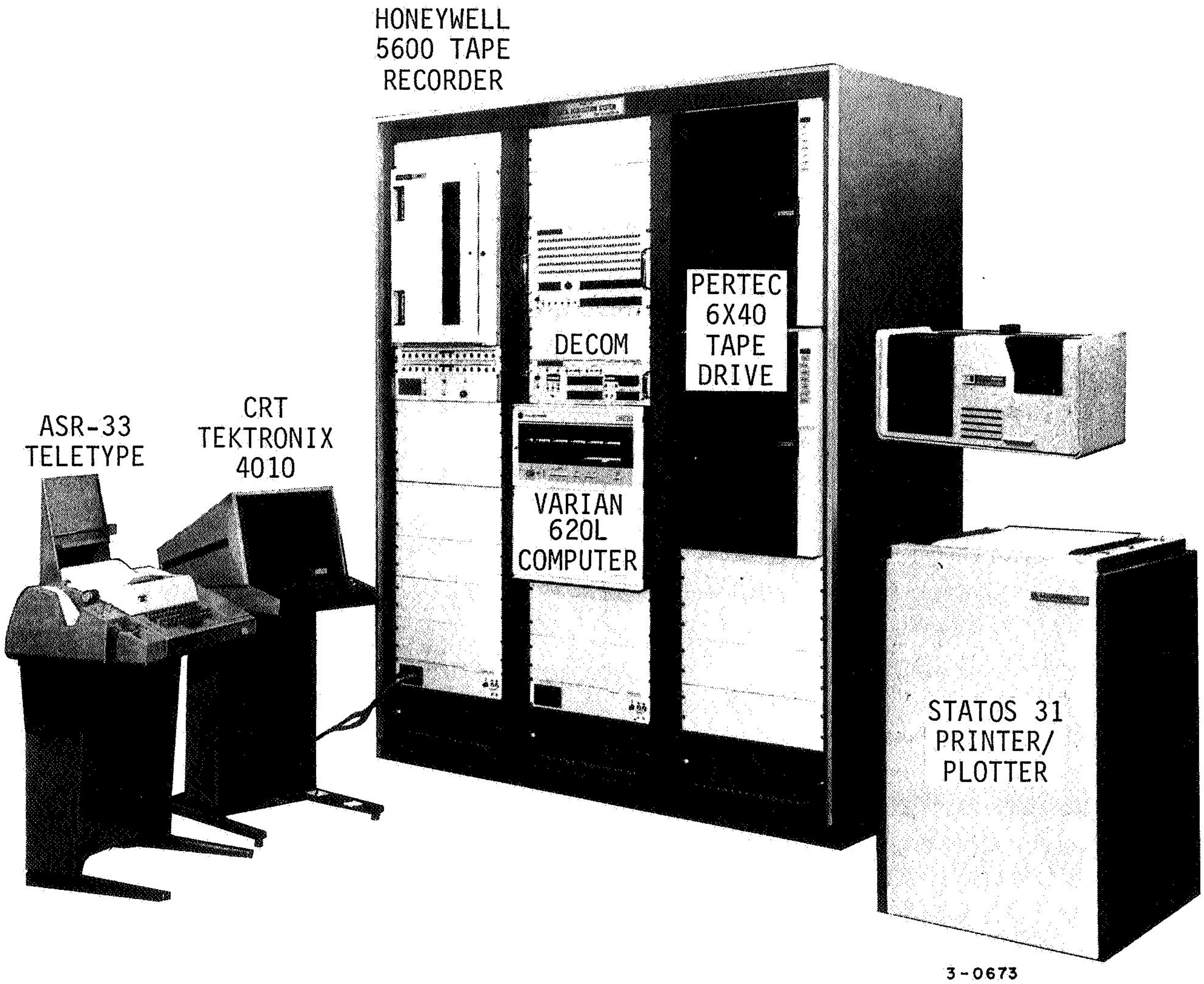

Figure 2.- Varian 620L computer system.

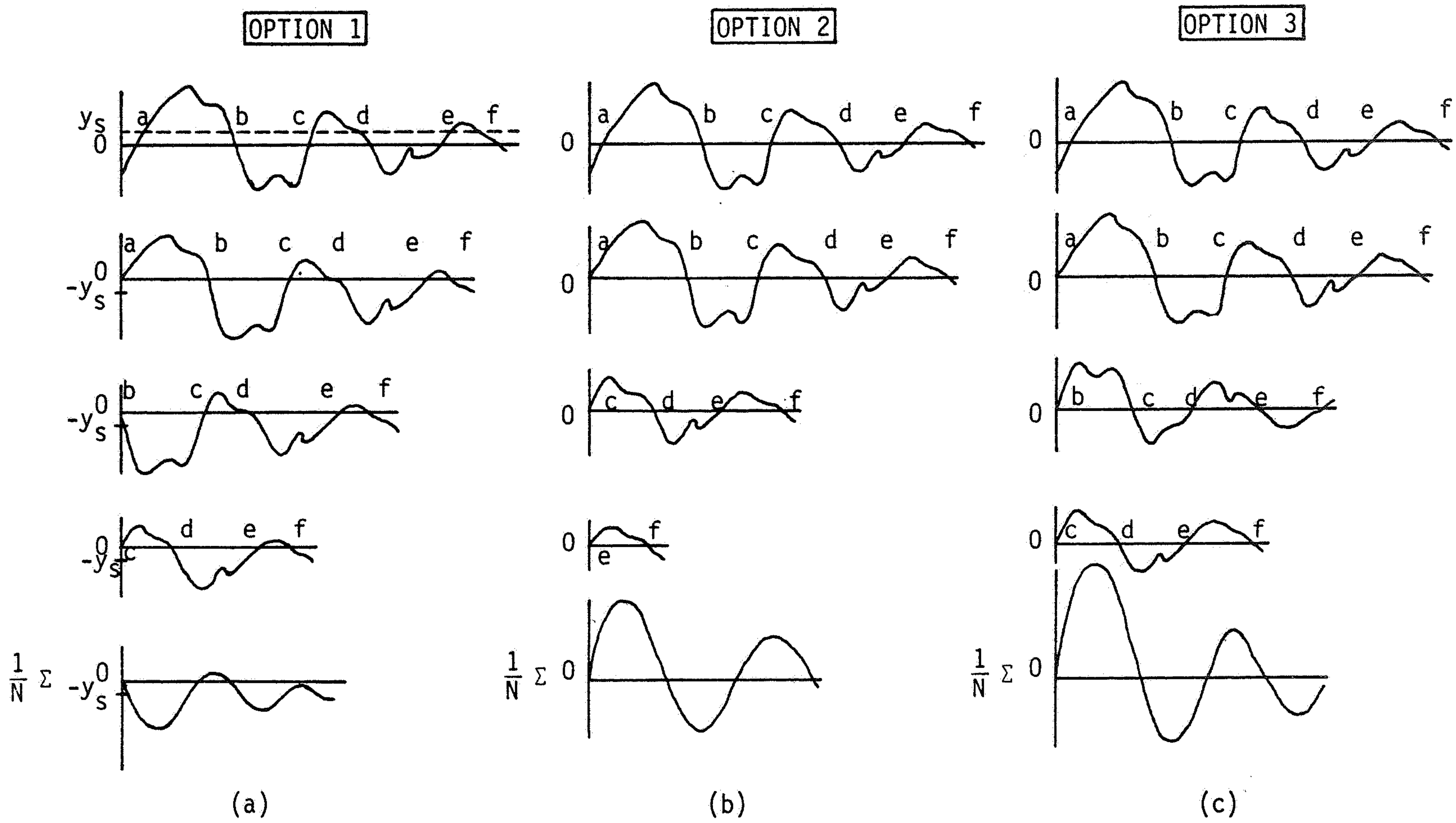

Figure 3.- Randomdec methods.

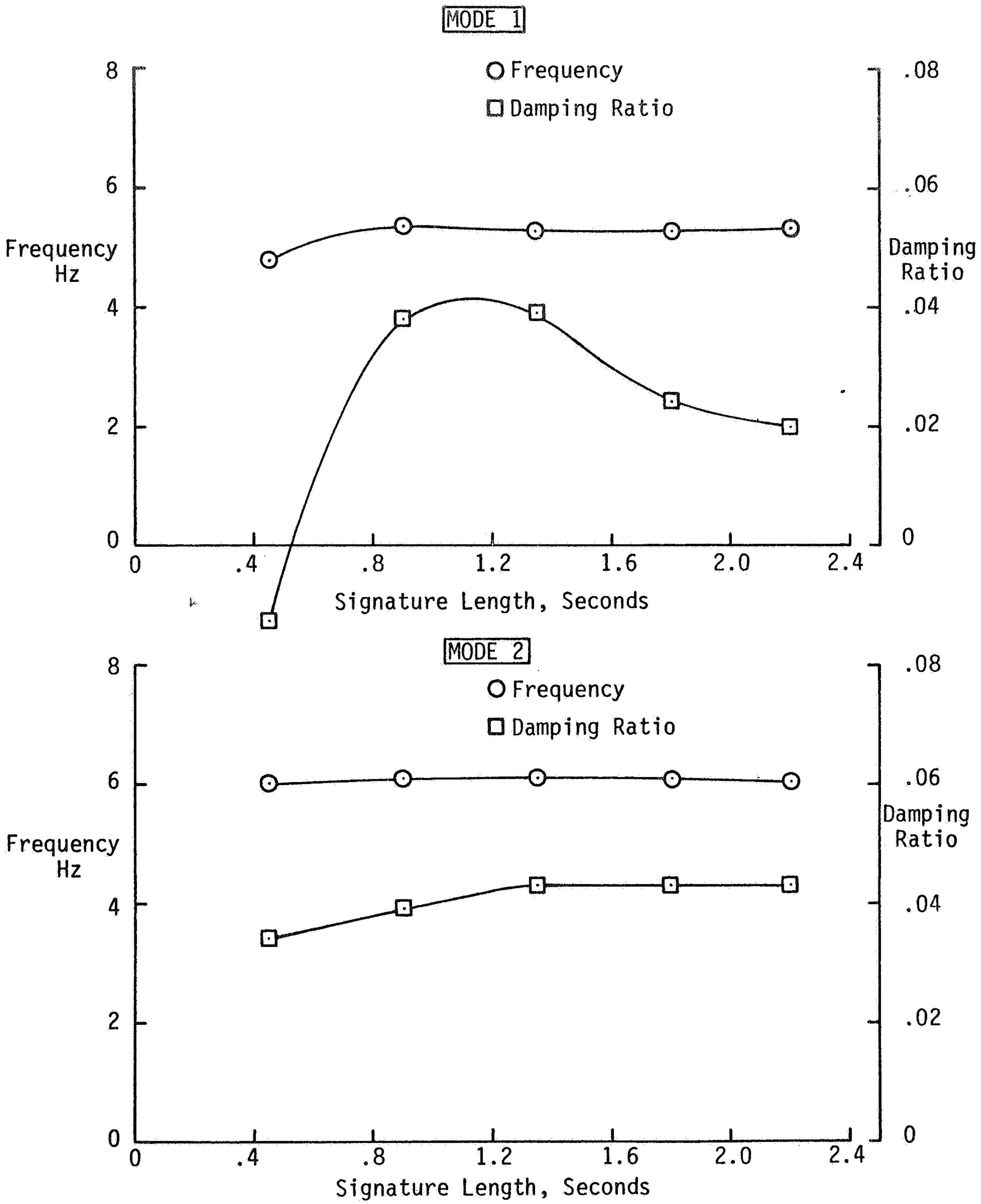

Figure 4.- Modal characteristics versus signature length using sinusoidal excitation at 250 knots.

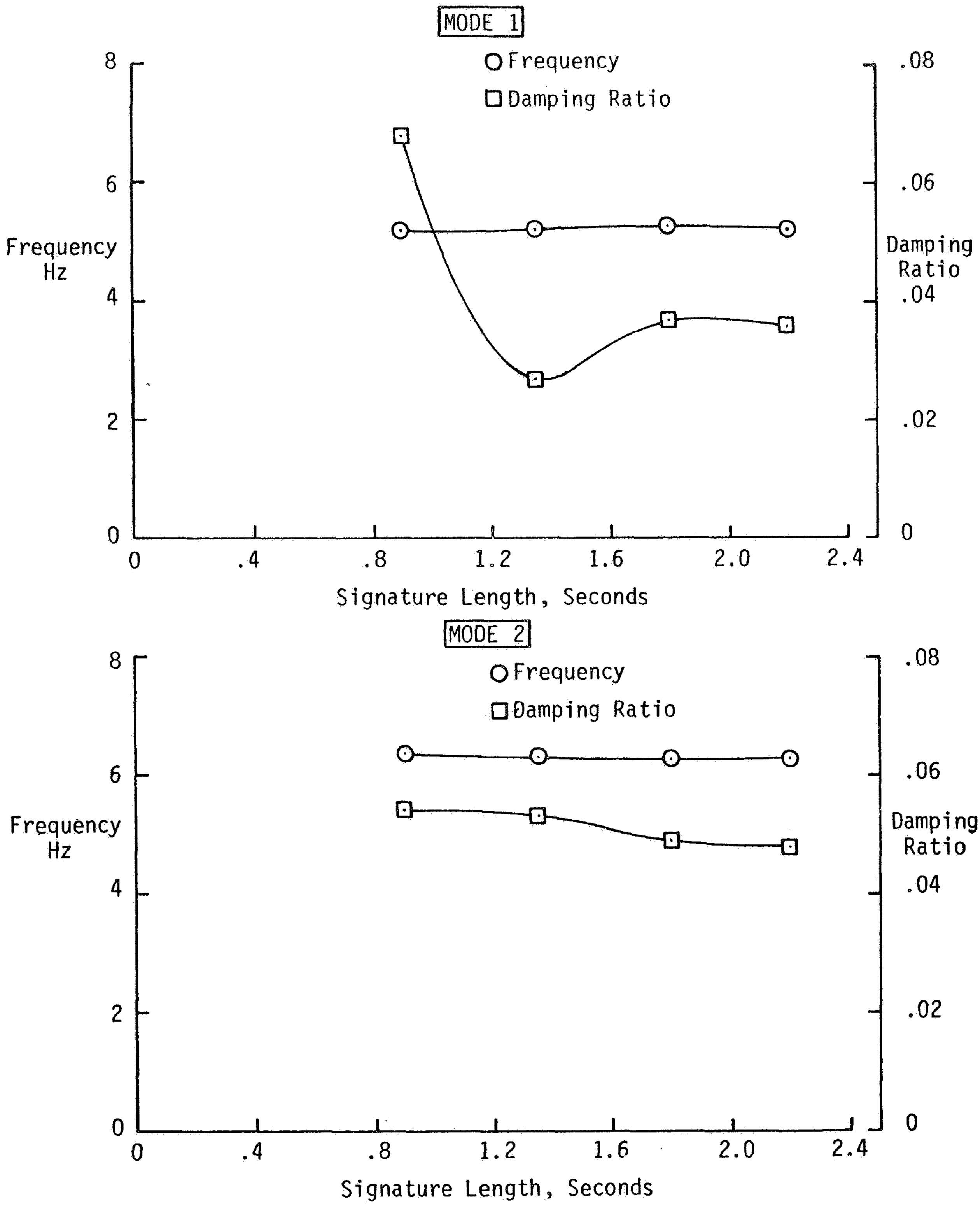

Figure 5.- Modal characteristics versus signature length using sinusoidal excitation at 350 knots.

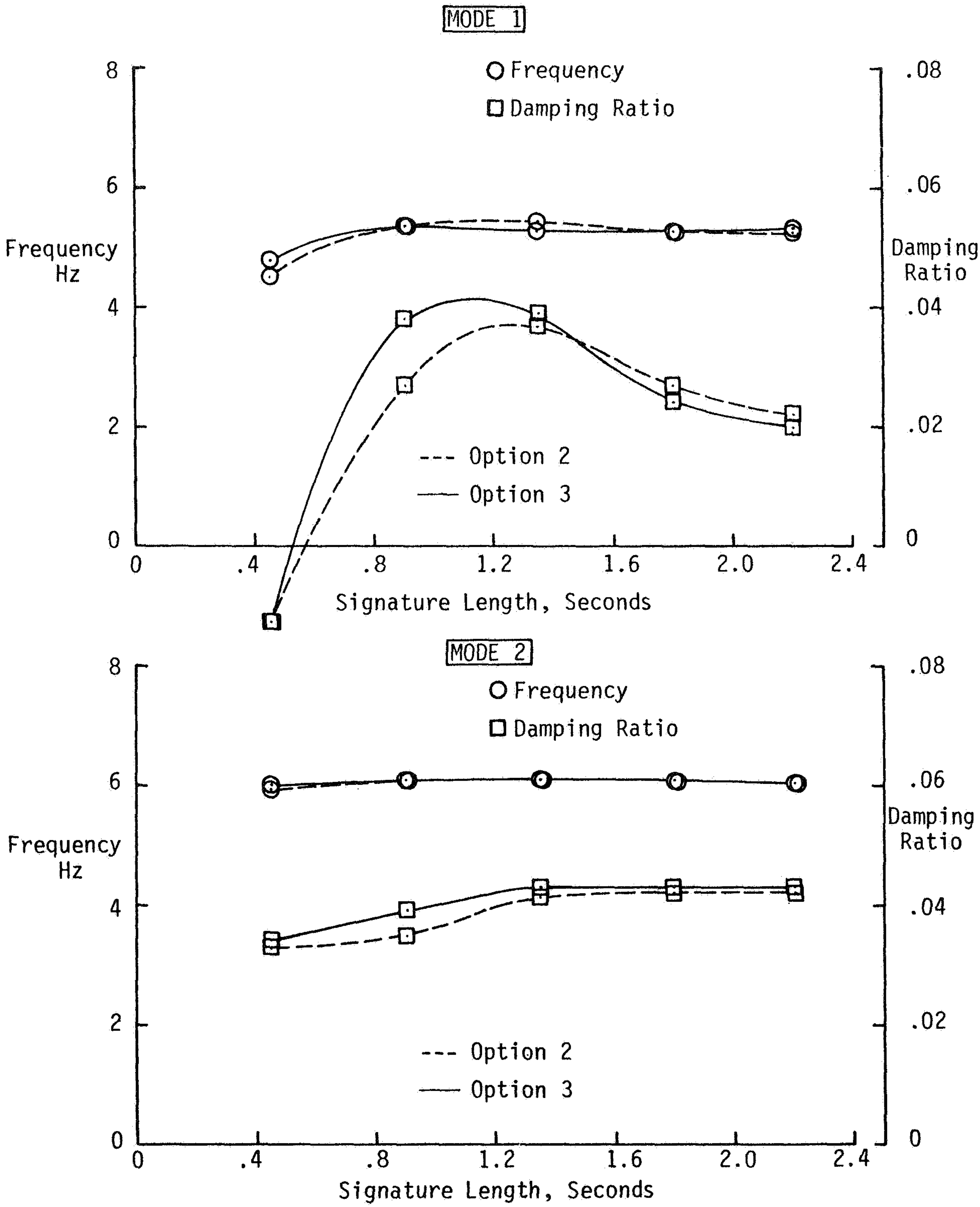

Figure 6.- Randomdec analysis using options 2 and 3 at 250 knots.

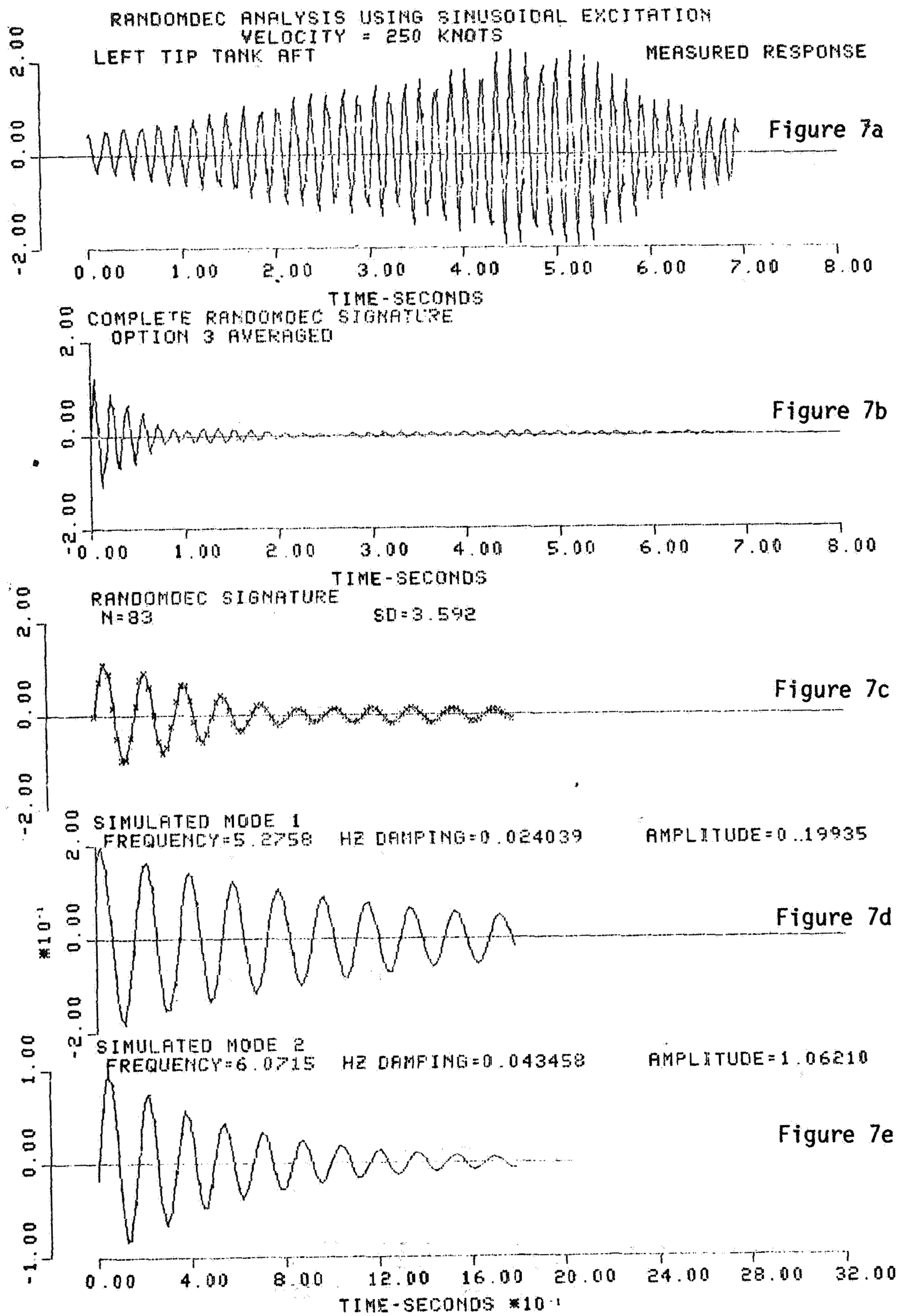

Figure 7.- Randomdec analysis using sinusoidal excitation at 250 knots.

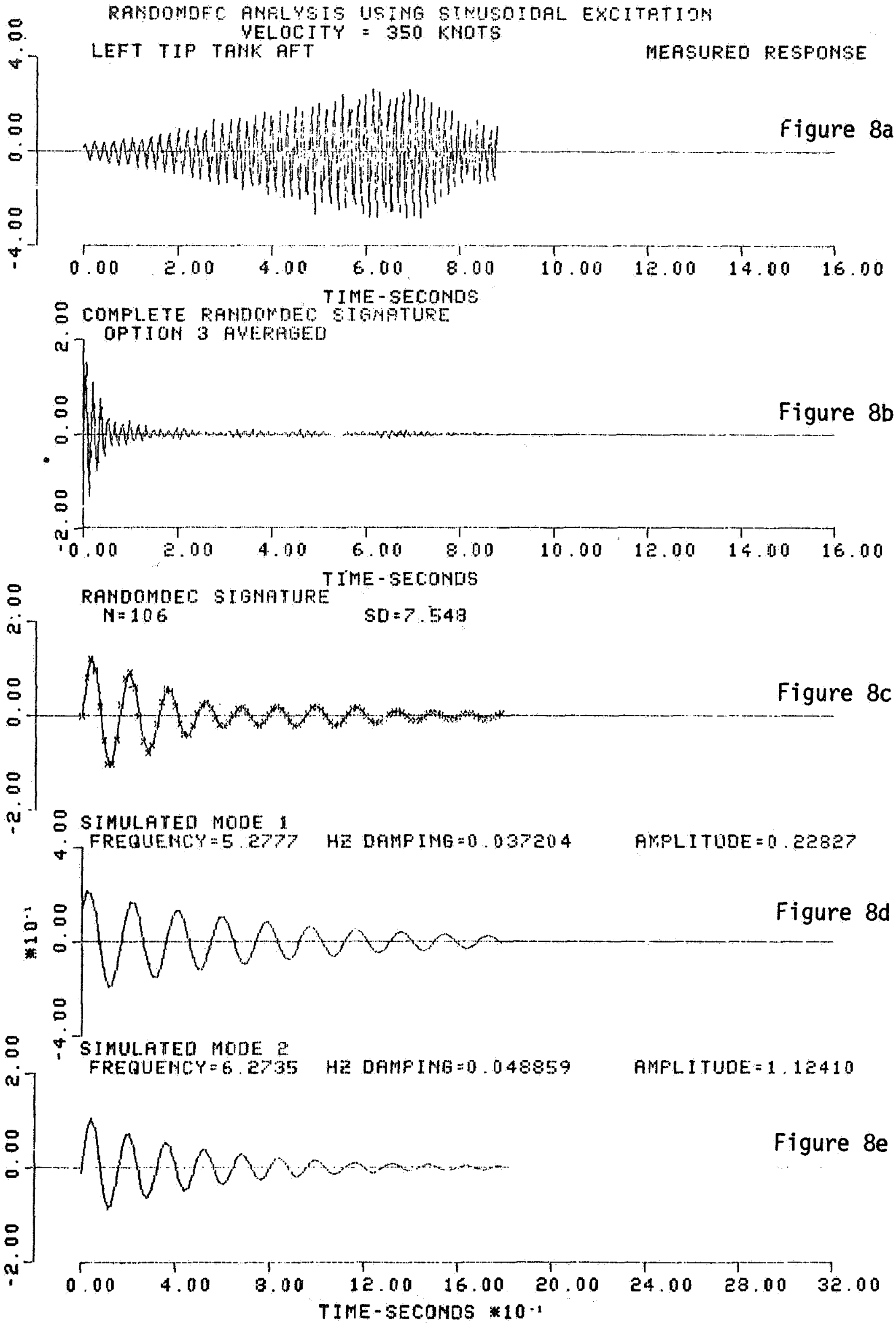

Figure 8.- Randomdec analysis using sinusoidal excitation at 350 knots.

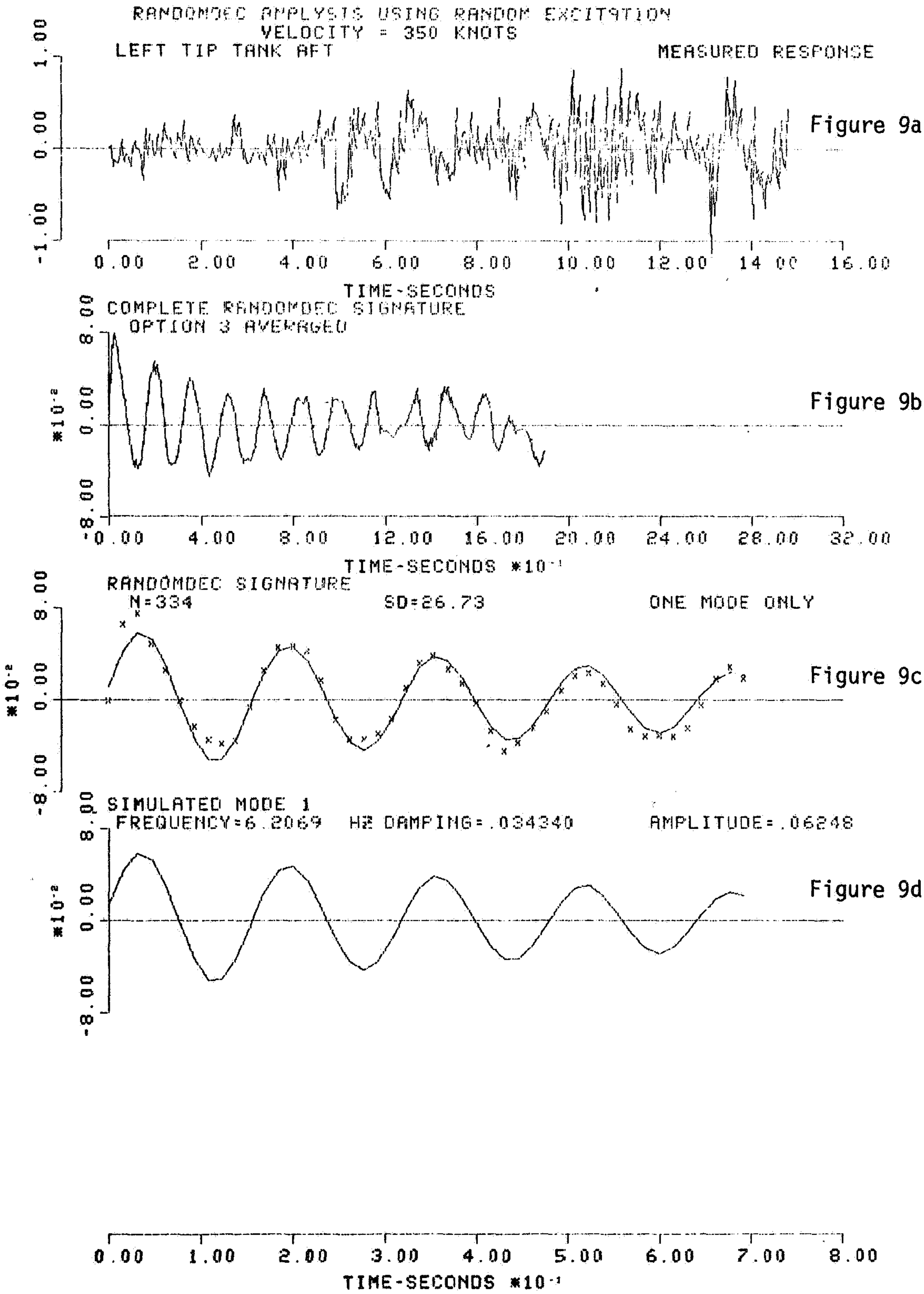

Figure 9.- Randomdec analysis using random excitation at 350 knots.

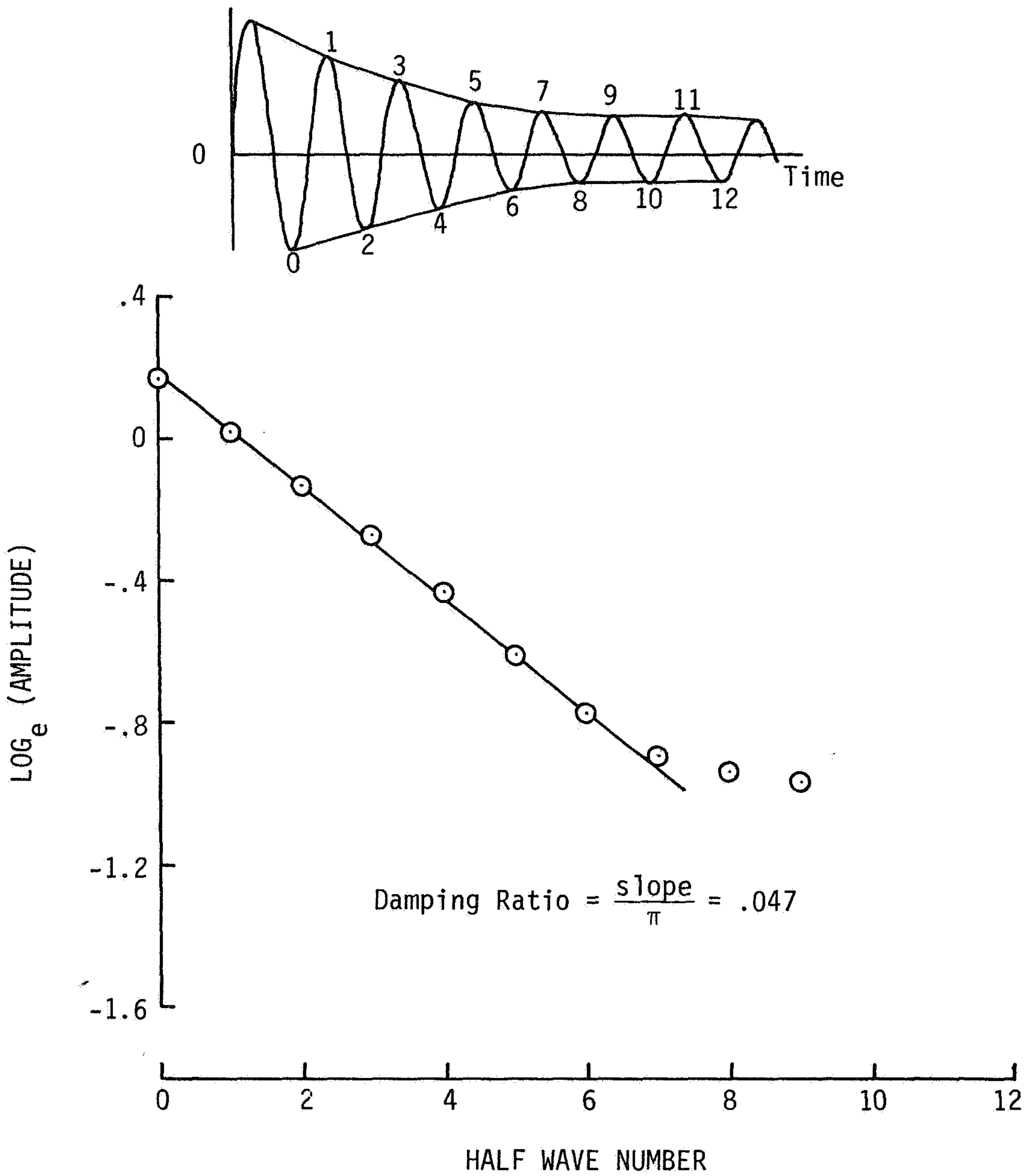

Figure 10.- Logarithmic amplitude at 350 knots.